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Meteorological Research
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BY
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METEOROLOGICAL RESEARCH AND FRUIT PRODUCTION.

By H. V. Taylor, O.B.E., B.Sc., A.R.C.S.

Some effects of the Weather on Fruit Production with special reference to the Apple Crop.

PART I.

THE WEATHER AND FRUITFULNESS.

Apples are grown in very many countries and their susceptibility to the influences of varying climates has been well tested. In this country they are grown in Kent and the Eastern Counties where the annual rainfall does not much exceed 25 inches, and also in the West of England where over 40 ins. of rainfall is often experienced. The apple district of Nova Scotia has a very heavy annual rainfall while that of British Columbia is less than 12 ins. In these districts and also in Tasmania and the United States of America the summers are rather dry and the winters cold and wet, whereas on the high veldt of South Africa where apples are grown, the climatic conditions are the very opposite, for the rainfall comes mainly in the summer, whilst the winter is, on the whole, dry with almost daily sunshine.

As the apple tree flourishes and gives satisfactory crops under these very different climatic conditions it might be thought that this plant is little affected by climate, an assumption, however, which it would be incorrect to accept. In fact, judging by the few investigations that have been made, the opposite seems to be nearer the truth, namely, that the climate (and especially rainfall, light and temperature), influences the tree and the crop it bears to a very marked degree.

Climate and Fruit Bud Formation.

It is necessary not merely to consider the effect of spring frost at blossoming time, which is a popular and annually recurrent topic, but to probe deeper and to trace the effect of climate on the growth of the tree and the influence that it brings to bear in causing the tree to form strong fruit buds, which are initially necessary for fruitfulness. To make this clear, it is necessary to ascertain the ordinary behaviour of a normal tree growing under varying conditions of climate and then, if possible, to trace therefrom the part that climate plays. This aspect of the problem has engaged the attention of research workers in this country, notably B. T. P. Barker and A. H. Lees at the University of Bristol Horticultural

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Research Station, Long Ashton, Bristol, from 1915, and their results are given in a series of papers in the Annual Reports of that Station for the years 1916 to 1920.

Tree Growth in a Normal Season.

From a study of the growth of the apple trees in the plantations at Long Ashton, Bristol (where the annual rainfall is high), these investigators came to the conclusion that three distinct stages in tree growth could be recognised. The first stage covered the period between approximately March 14th and April 12th during which an even and regular slow movement was made by all buds. This movement might be described as an awakening from the winter sleep of all buds in response to the stimulus of warmth.

With the passing of this stage, soil moisture diminished, whilst a very uneven extension growth was made by the different buds. The terminal buds seemed to have a preference for they grew much faster than the others; less growth was made by the buds in the middle of the shoots, whilst those at the base remained more or less stationary. This was regarded as the second stage and the period lasted from approximately April 12th till May 20th.

The tree growth then entered the third stage; bud growth slackened very considerably; only a few buds at the apex continued to form *woody* shoots, and these one by one came to a standstill so that in a normal season growth was completed by about August 15th. Such was the behaviour of an apple tree growing at Long Ashton in what might be termed a dry season.

Tree Growth in a Wet Season.

In the wet seasons it was noticed that the bud growth instead of stopping in the middle of August was continued until September 30th with the result that the wood of the tree was not properly ripened and much wood unfurnished with fruit buds was formed. As will be shown later this extended autumn growth in wet seasons plays an important part in rendering trees unfruitful, for this continued growth uses up the food material and prevents the tree from laying down food reserves which are so necessary for flower blossoms and fruit production. A continued study of this subject convinced A. H. Lees of the very great influence on fruit production of this summer and autumn rainfall, for in an article published in the *Journal of Pomology and Horticultural Science*, Vol. V., No. 3, July, 1926, he analysed the influence of summer rainfall and previous crop in the fruiting of apples. He described the normal growth phase of the apple and concluded:

> "that just as the basal buds are the weaker so the fruit spurs developed from them are weaker. So weak are they that it may be years before they attain sufficient strength to flower. Those nearer the apex are stronger and may flower

next year, whilst the nearest may be so strong that their axis is three or four inches long and their terminal a wood bud and not a flower. There is therefore a distinct gradient in strength; the weakest are too weak to form flowers, the medium are just in the right condition, while the strong do not cease growth in length soon enough in the season *to store sufficient food for flower production.*"

It is thus suggested that to be in a fruitful condition the growth of the tree should cease early—not later than the end of July—so that reserves of food material may be stored within. Stimulated by summer and autumn rainfall, tree growth beyond that date may be prolonged which results in the using up of the food material, and in preventing the laying down of sufficient reserves to make strong and fruitful buds. In other words late summer growth—which is the result of excessive rainfall—is parasitic on the food supply that normally should be laid down as reserves for the buds.

Summer Rains and Crop.

It was recognised by Lees that the crop of growing apples would also make heavy demands on the food material, and in consequence he considered this factor (the crop) and the summer rainfall as the predominating influences on the future fruitfulness of a tree. From a study from year to year of these two factors he found that it was possible, with certain exceptions, to forecast with some accuracy the size of the crop to be expected. The exceptions are explained by abnormal Aphis attacks or the adoption of fresh methods of manuring or pruning, and if these exist an allowance must be made. Briefly, in forecasting the grower was advised to make use of the following scheme:—

Crop.	Rainfall.	Estimated succeeding Crop.
Heavy	Wet	Very poor.
	Medium	Poor.
	Dry	Medium.
Medium	Wet	Poor.
	Medium	Medium.
	Dry	Good.
Light	Wet	Medium.
	Medium	Good.
	Dry	Very Good.
None	Wet	Good.
	Medium	Very Good.
	Dry	Very Good.

A. H. Lees even went so far as to suggest that it was quite possible to throw trees into continuous cropping by regulating the manurial and "water factors" in the right direction. An alteration

of the "water factor" can be effected by temporarily withholding manure, by cropping with a cover crop and by the practice known as "ringing."

Rainfall and Grass Orchards.

Another observer of the effect of rainfall on fruitgrowing is A. H. Hoare, who, in his book "The English Grass Orchard," expressed the view that:—

> "It is hardly possible to grow fruit successfully for market in a district receiving anything in excess of 40 ins. of rainfall. At between 30 and 40 ins. fruit may be grown, but the orchards are mostly on the grass orchard principle, as we find on the Bristol side of Gloucester and in Somerset. In the regions of 25 to 30 ins. fruit may be grown in either cultivated or grassed land. Below 25 ins. fruit will do well on holding land. It might be laid down, therefore, that the best fruit districts are those with an average rainfall not higher than 30 ins."

Certainly, the fruit growing districts in England are in regions where the rainfall is similar to that suggested above. In Switzerland and Austria, where, generally, the sunlight intensity is far higher than that of England, the trees are not harmed by further supplies of water, but rather benefited, so it seems that rainfall—important as it is—is not the sole factor regulating fertility. As just indicated, intense light has a decided influence.

The Influence of Light on Tree Nutrition. The Carbohydrate Nitrogen Ratio.

The amount of summer rainfall and the light intensity influence the internal condition of the tree, which governs its fruitfulness or unfruitfulness.

Certain American research workers, especially Kraus and Kraybill, have attempted to measure this internal condition by ascertaining the ratio of carbohydrate to nitrogen present in the cell sap—a method which has aroused much interest.

The amounts of carbohydrate and of nitrogenous substances in the cell sap depend very much on the activities of the leaves and roots respectively. Under the action of bright light, the leaves are able to synthesise, from the carbon dioxide and water vapour, taken in from the atmosphere, some of the simple forms of carbohydrates; and these types of food material are essentially products of leaf manufacture. The amount of carbohydrates manufactured by the leaves naturally depends on more than one factor, but as the action is one depending on the influence of light on the chlorophyl, the intensity of light more or less exercises a predominating influence. In summers of intense light more carbohydrates are manufactured in the leaf than when dull light is experienced.

On the other hand, nitrogenous substances in the cell sap find their way into the plants in solutions absorbed by the roots, for it is the watery solution that is taken up by the root hairs. If the soil water is deficient, less of the nitrogenous constituents in the soil are dissolved, and a smaller quantity is taken up by the root hairs. Where the summer water supply is abundant and the soil is heavily supplied with nitrogenous substances, there need be no check on the entry of nitrogenous matter into the plant.

The Work of Klebs, Kraus and Kraybill.

An American worker Klebs, has found that plants remain vegetative in bright light with a plentiful supply of water and nutrients, or in moderate light with a moderate supply of water and nutrients, but that they blossom after growing in *bright* light with a *moderate* supply of water and nutrients. Klebs apparently did not attempt to explain the reasons for this. Then came Kraus and Kraybill who in experiments found that most of their fruitful tomato plants were *moderately low* in nitrogen and high in carbohydrates. Fruitfulness then was associated neither with the highest nitrates nor with the highest carbohydrates, but with what the workers termed a condition of balance between them.

The limitation of nitrates or the limitation of carbohydrates resulted in a suppression of growth in tomatoes. When carbohydrates and nitrogen were adjusted relative to one another, rapid vegetative extension resulted. Where carbohydrates were in excess such an adjustment was secured either by increasing the nitrogen without decreasing the carbohydrate or by decreasing the carbohydrate without increasing the nitrogen. In both cases the relation of carbohydrate to nitrogen would be the same, but the total amounts were greater in the former than in the latter case, a condition reflected in the amount of growth resulting. The ratio of the carbohydrate to nitrogen determined whether the plants were to be fruitful or unfruitful, whereas the amounts present influenced the size of the crop.

Since this discovery was made known, much further work has been done regarding the connection between plant fruitfulness and the *carbohydrate nitrogen* ratio, with the result that the hypothesis has been firmly established by most workers and it is accepted in most countries. Whilst the exact rules for managing fruit trees to make them fruitful still remain hidden, the discovery marks an important step forward, establishes a new principle and makes it possible for the observant person to carry out the management of his orchards in a more intelligent manner. In fact it is seen that the fruitfulness of fruit trees in all countries rests on a scientific basis and the method of treatment and manuring must be varied from country to country to offset the weather effects, if this proper balance between the carbohydrates and the nitrogenous substances is to be maintained.

In the U.S.A., where the summer rainfall is small and the light intensity is very high, it is conceivable that the leaves and trees are able to store up vast quantities of carbohydrates, and that in consequence fruit trees would respond to dressings of nitrogenous manures. Actually this has been found to be the case and is instanced in the following paragraphs taken from the U.S. Department of Agriculture Year Book, 1925.

Nitrogenous Manures in American Orchards.

During the past 15 or 20 years much experimental work has been done in the use of commercial forms of plant foods in orchards . . . . . At least three outstanding results have come from these investigations :—

(1) Of these results, first, may be mentioned the demonstration that many soils when managed so as to maintain an abundant supply of humus, and when properly tilled, apparently yield all the plant food that is necessary for maximum fruit production.

(2) Another result, and one opposed to earlier teachings is the widespread absence of favourable response of fruits to potash. It was long held that fertilisers high in potash should be used liberally in fruit growing. Many tests, widely distributed, have failed to demonstrate any general response to applications of this plant food, especially on soil types widely used for deciduous fruit growing.

(3) It was long taught that nitrogen, and especially in quickly available forms, should be applied to fruits with much caution or else an undesirable and harmful stimulation of vegetative growth would occur. In the demonstration, not only have baneful results failed as a rule to appear, but to the contrary, the use of nitrate of soda or other quickly available forms of nitrogen, in even rather liberal quantity, has given more widespread and more generally beneficial results than any one fertiliser treatment in the growing of deciduous fruits."

Potash Fertiliser in English Orchards.

Trees in England growing in a soil more abundantly supplied with summer moisture, and working in a duller light, are more likely to have a greater root activity in absorbing nitrogenous substances, and to manufacture relatively less amounts of carbohydrates. In other words the carbohydrates may be too low and in consequence trees (especially those growing in the West) are more likely to respond to such manures as potash which helps the plant in some unexplained way to make the most effective use of sunlight, than to dressings of nitrogenous manures alone. The experimental

work done at Long Ashton by T. Wallace has shown this to be the case. Very many cultivated orchards, particularly those on the light soils, have been found to produce unfruitful trees, which make little or no response to nitrogenous matter, but become more healthy and productive after repeated annual dressings of potash fertilisers. Wallace's experiments and the results of the soil survey work in England during the past four years have shown that the leaves of the trees in these orchards are in a poor condition, commonly called "scorch," which is known to be associated with potash deficiency. When potash is added such trees improve; fruitfulness is restored or improved and increased growth is made.

Where fruit plantations in England are cropped also to grass, the roots of this cover crop compete with those of the trees for both water and nitrogenous fertilisers, and in time the leaves on the trees—even those growing in the west of England—gradually lose their dark green foliage and take on a yellowish light green colour which is said to be a sign that the nitrogenous substances have become too low. In such cases nitrogenous manures have been found to have beneficial effects in improving the fruitfulness of the trees both in quantity and quality of the fruit produced.

If this correct balance between the amounts of carbohydrates and nitrogenous substances is an essential condition to the fruitfulness of the tree—and all the experiments on the point seem to confirm that such a balance *is* essential—then the management of orchard fruit resolves itself into an adjustment, by pruning, manuring or cover cropping, of the inequalities produced by the natural soil and the prevailing weather in each locality. Of these it seems that the prevailing weather—rainfall and sunshine—is the more important, for the chemical or even physical analysis of the soil seems to provide little information as to its suitability for fruit growing or to provide any pointer as to the proper manurial dressing.

Fruit Soil Surveys.

This does not mean that the fruit soil surveys that have been carried out in the past are useless or that those now being conducted will yield valueless results. It does mean, however, that the surveys must be made in a different way so that the reactions of the trees (in growing and cropping) on soils in any locality must be recorded as additional important factors for these give an intelligent observer a greater understanding of the conditions than even a detailed study of the chemistry of the soils. The appearance of the foliage of trees, their rate of growth, their fruitfulness or unfruitfulness, and their susceptibility or resistance to many diseases and pests are visible expressions of balance or lack of balance in the cell sap produced by the local soils and the prevailing weather. It is on these lines that the present fruit soil surveys are being pursued in England with very hopeful results. Up to the present the surveys have been of fruit on the soils in the Wisbech Area

where the water table was thought to be more or less constant; on the old Red Sandstone in the West Midlands; and in West Cambridgeshire. Other surveys are contemplated or are in progress for trees on the soils (mostly sands, Lias clays and marls) in Worcestershire and Somerset, and on the varied soils of Kent.

Such surveys are providing information of the greatest value to the Advisory Service so that its members in future will be able to tackle the fruit problems with which they are confronted, with intelligence and a better understanding. Fruit trees in Worcestershire —where the rainfall and sunshine are fairly uniform for the whole county—react very differently when planted on the sands, the Lias clays or the marls, though in main the reaction is fairly regular on each type of soil. Stunted and hollow trees with much leaf scorch and signs of susceptibility to "die-back" on the sands give a striking contrast to the vigorous and healthy trees on the marls, or the large though somewhat chlorotic trees on the Lias clays. These strikingly different results are produced by the soils and the prevailing weather. Under different weather conditions trees on similar types of soils would react quite differently. It is the recognition of the combined effect of weather and soils in the growth of trees and their fruitfulness that is preparing the ground for a more intelligent method of orchard management for trees on each soil type in any locality.

So hopeful have been the results from the soil surveys made on these lines that the need for their extension to all the fruit areas of this country is admitted by those concerned. It is a line of investigation worthy of the utmost support by Departments interested in agricultural meteorological research.

Whilst this influence of the weather on the fruitfulness of trees seems the most important to the author it is a view that would not be universally accepted, for where the effect of weather on the fruit crops is in question, the majority of people think in terms of frost damage at blossom time. It is therefore advisable to set out in Part II of this paper the more modern views on the latter subject and also the methods that have been tried to prevent frost from damaging the blossoms.

PART II.

FROST DAMAGE TO FRUIT BLOSSOMS.

When the fruit trees are in full bloom growers are very apprehensive of the weather conditions and fear wholesale destruction as soon as temperature falls to a low point. Frosts are feared by most, and winds by some, though a few suggest that the danger has been much over-rated. A. H. Lees of Long Ashton, for instance, has cited a case of plums which were in full bloom when there came a snowstorm which covered the plums completely. Later in the day the snow partially melted and toward night froze again. All night the blooms were locked in ice and dire prophecies of failure were made. Actually a heavy crop was set. In consequence Lees contended that the danger from spring frost was exaggerated except in certain situations where, owing to the configuration of the land, a natural reservoir for cold air was formed.

In the spring of 1927 severe frosts occurred throughout the various parts of Kent (England) during April when the temperature fell to 19° (thermometer on grass at East Malling). Wholesale havoc was expected and no doubt much damage was done, but it must be recorded that the apple crop in that year was above the average though the other fruits were somewhat below. Experiences such as these lead people openly to say that the spring frost is a bogey when actually there are times when spring frosts may be very harmful. At the East Malling Research Station records of both weather and crops are kept and it is interesting to set out the notes on both that were separately recorded each year in the annual reports. The results are as follows :—

Relation of Fruit Crops to Spring Weather at the East Malling Research Station.

Year.	Spring Weather Report.	Fruit Crop Report.
1924 ..	Temperature departed little from normal.	Very heavy crop of small fruits and apples.
1925 ..	Normal	Heavy crop of apples and black-currants. Raspberries affected by drought. Plums and pears disappointed.
1926 ..	First days of April summer-like when plums, early cherries and apples were in blossom. Conditions during blossoming wet and cold.	Plums above average. Black-currants average. Early apples and early cherries good. Late flowering varieties poor.

Year.	Spring Weather Report.	Fruit Crop Report.
1927 ..	Devastating frosts during April, especially April 27th and 30th.	Good blossoming but frost damage. Apples below average, others poor. Black-currants the most satisfactory.
1928 ..	Ground frosts at blossoming time of similar severity to 1927, but not so destructive to crops.	Apples good. Pears failed for third time. Frost and cold winds said to be responsible. Plums variable.

It will be seen from this that heavy crops were obtained in the years 1924 and 1925, when the weather was normal, but that in 1926 the fruit that came into blossom during the cold, wet period gave poorer crops than that which blossomed under good conditions. In 1927 frosts in late April were followed by inferior crops and the same occurrences, though less marked, took place in 1928.

County Reports of Frost Damage.

Consequent on the very severe frost at the end of April, 1927, the Ministry of Agriculture called for special reports at the end of May concerning the effect of these frosts on the fruit prospects. Twenty-nine reports were received and all made mention of severe damage to the fruit blossoms. Here are a few examples:—

Hampshire.—Strawberry blossoms that were open were attacked. The embryo flowers were also killed, particularly the style and stigma. High elevations as well as low caught the frost (8–15° F. registered) equally. The pick of the blossoms were killed and there is little high-class fruit to come—though the " back fruits " have made a good recovery.

Worcestershire.—First Reporter.—Practically all fruits have been affected but more especially the plums and cherries, some varieties of plums losing 95 per cent. of the blossoms. Apples were late in coming into bloom and with the exception of " Grosvenor " they have escaped serious damage. Most varieties of pears have been badly damaged.

Worcestershire.—Second Reporter.—In the low-lying parts the damage to plums is estimated at 90 per cent. as the result of temperatures as low as 14° F. On the favoured high ground the effect of the frost is hardly perceptible. In some cases it is very difficult to account for the frost damage in plantations joining one another, the one being badly hit whilst the other has scarcely suffered.

Pear bloom was unusually profuse just at the time of the frost with the result that there are no pears, except Williams.

Eastern Counties.—The incidence of frost damage has been most erratic. Orchards protected by rows of trees or closely planted have escaped the most lightly, whilst in bleak positions the damage has practically wiped out the crop.

Norfolk.—On the whole, plantations of black currants lost about 50 per cent. of blossoms through the frost. A few plantations escaped injury.

Hereford.—A frost varying from 11–13° F. occurred on the night of April 29th–30th, accompanied by a strong wind N.W. to N.N.W. Only fruit blossoms protected from this wind and at fairly high altitudes escaped damage. In many orchards the crop was totally lost but in exceptional situations very little damage occurred. Within these extremes, representing the bulk of the plantations, damage of varying severity was experienced.

Kent.—Most frost damage appears to have been experienced in the low-lying pockets, though some damage was experienced at all altitudes up to 400 ft. above sea level. High districts escaped. Generally, the frost damage has reduced the total crop very much less than was at first anticipated.

The following are taken from reports received in 1928:—

Warwick.—A series of frosts—varying in intensity from 5–10° F.—was experienced between the 16th-23rd of April, with the result that much damage was done to fruit trees in flower. Very few apples were in flower and on some sites but little injury is apparent. In low-lying positions, although the petals of the unopened flowers are intact, yet the vital organs have been destroyed. Plum trees had just passed the flowering stage and a large proportion of the fruitlets are black—though a sufficient number have escaped injury.

Norfolk.—Bitter cold winds and frosts at night up to 10–12° F. have damaged 25 per cent. of the plum blossoms. Other fruits are less affected.

Kent.—Weather conditions during March and April have been adverse for insect pollination; otherwise injury is very slight.

Isle of Ely.—Ground frost on April 6th, 12° F. Apples, frost injury negligible. Plums, some injury. Pears, most blossoms ruined. Strawberry flowers blackened.

Worcestershire.—Apples—some frost damage, particularly in the valleys. Victoria plums severely damaged on the low ground. Strawberry flowers blackened.

Devon and Cornwall.—Frost on 16th April. Pears were caught in full bloom and much browning took place. Plums suffered severely. Strawberry blooms blackened.

Cambridge.—There is no evidence to show that there has been very much damage. Plums in exposed areas have suffered from cutting east winds and in sheltered spots where frost pockets have formed. In the main I think that the dryness of the air to a large extent saved the situation.

Middlesex.—Plums everywhere seem to have suffered. Pear injury is not so general and apples show no damage.

Herefordshire.—A frost on March 12th from 18–22° F. at which time the Baldwin black currant was just showing flower. The blossom trusses are quite brown ($\frac{1}{4}$-in. long) and the loss over the whole area will be 5 per cent.

These reports made by experienced horticulturists as the result of personal observations clearly show that under certain conditions intense cold may actually kill the vital organs of the blossoms of all kinds of fruit and thus make it impossible for such blossoms to produce fruit. The degree of cold seems important, though severe damage seems to result only when the fruit (with certain varieties excepted) is either in full blossom, or nearly so, and becoming ready for fertilisation. The damage seems to be intensified when a cold and biting dry wind is also present.

There is a unanimous opinion, too, that frost injury is more severe in the valleys and low-lying ground, though many observers continually refer to damage in "frost pockets"—whatever that may mean—and also state that "air drainage" prevented frost damage.

If any wide investigations were contemplated it would seem advisable to study tracts of land to discover the altitude below which it is inadvisable to plant fruit, and to find out exactly the causes of a "frost pocket" in an otherwise frost free area and to ascertain what "air drainage" means also.

Frost Susceptibility of Certain Varieties.

In the above-mentioned enquiry, observers were asked to notice particularly the comparative injury caused to the several varieties of fruit with a view to ascertaining whether all were equally affected or whether some appeared to possess more resistance than others to frost. The results obtained are more definite and interesting than were expected.

The damage done to several varieties of fruits, classified under the headings of "severe damage," "damage," "slight damage" and "unaffected" was as follows:—

Differences between Varieties of Fruit in the Degree of Damage caused by Frost.

Severe Damage.	Damage.	Slight Damage.	Unaffected.
		Apples.	
Bramleys	Court Pondu Plat Beauty of Bath	Cox's Orange Stirling Castle Worcester Pearmain Lord Grosvenor James Grieve Warner's Lane's Early Victoria Bismarck Lord Derby Newtons (var.) Allington Ellison's	Wellington Irish Peach Royal Jubilee
		Plums.	
Victoria Monarch Greengage	Pershore Egg	Czars River's Early Prolific Ponds Seedling Purple Pershore Belle de Louvain	

Severe Damage.	Damage.	Slight Damage.	Unaffected.
	PEARS.		
Conference		Fertility	Hessle
Louise Bonne de Jersey		Durondeau	
Beurre Bosc.		Doyenne du Comice	
Williams			
Beurre Hardy			
Clapp's Favourite			
	BLACK CURRANTS.		
	Baldwin	Seabrook's (Black)	
	Boskoop		
	Edina		
	GOOSEBERRIES.		
Whitesmith	Lancer	Lancashire Lad	
White Lion	Careless		
Gunner	Keepsake		
	STRAWBERRIES.		
Sovereign	Bedford	Mde. Kooi	
Laxtons	Champion	Paxton	
	The Duke	Stirling Castle	

Naturally there was some conflict of opinion concerning some varieties but unanimous opinion existed both in 1927 and in 1928 that with apples Bramley suffered the most damage, and that Cox's Orange, Lane's, Worcester Pearmain, Lord Derby, Allington and Newton Wonder, were less susceptible.

With plums the variety Victoria suffered the most, Pershore the next, whilst Czar escaped with slight damage. These results were confirmed in 1928.

Of pears Conference and Clapp's Favourite were the most affected in all districts, and Hessle the least.

With blackcurrants the only positive result on which nearly all observers agree is that Seabrook's Black suffered the least.

With gooseberries Lancashire Lad seemed the most resistant and White Lion the most susceptible to damage. There was agreement that "Sovereign" Strawberries were severely damaged in all districts whilst Sir Joseph Paxton escaped with slight injury. A closer analysis of the respective behaviour must be left for future research workers who have a large and interesting field to explore.

So definite have been the conclusions regarding the susceptibility of Bramley apple, Victoria plum, Conference pear and Sovereign strawberry and also the definite resistance of several apples, Hessle

pear, Lancashire Lad gooseberry, Seabrook's black currant and Sir Joseph Paxton strawberry that it is clear that varieties differ considerably in their ability to withstand frost damage. An investigation of this kind can only point out the main problems and it must be left to the more careful and patient research work of scientific investigators to define more clearly the response to frost damage of the main commercial kinds. It is clear that the problem is important and worthy of further investigation.

Research Work already accomplished.

A certain amount of research has been done and it is proposed to set out in a concise form the facts on this subject that have been made known.

In the spring (April in England) the fruit buds of a potentially fruitful apple tree, receiving some stimulus from within, burst into blossom. The blossoms are composed of many parts; firstly there are the conspicuous pink and white petals—popularly called the apple blossom—whose main function is to attract insects to the flower; but having done this they fall and serve no further purpose in fruit production. The effective organs for this work lie within the petals; they are much smaller and much less conspicuous, and it is necessary to give some description of these and the functions they perform before the influence of the weather can be fully understood.

If the flower of the apple is examined there will be found, lying just within the pink and white flowers, a large number of thin filaments each carrying at the top little oval sacks, which on maturity —they do not all mature on the same day—burst open, scattering little yellow pollen grains, some of which get attached to the legs, wings and bodies of insects that visit the flower in search of nectar and are carried by these from blossom to blossom.

Blossom Fertilisation described.

Inside this whorl of filaments there are to be found others (the stigma) which are somewhat shorter, fewer in number and much stouter, particularly so towards their apex. On maturity the ends of these become sticky, a condition which remains for 2 or 3 days. Again these do not all mature at the same time. The pollen grain pitching on these sticky substances is not only held fast, but it absorbs water from the sticky substance, swells up and in consequence is stimulated to grow, which it does by sending out a germ tube. This tube is capable of pushing or dissolving its way down through the stigma filament into the swollen green tissue lying just at the top of the stem. The germ tube here reaches the sac containing the egg and has thus made a passage between the pollen cell and the egg cell.

These processes only take place under favourable conditions. Under adverse weather conditions the sticky mass may dry up, in which case the pollen cell is not stimulated to germinate; or, if the temperature be too low, the pollen again may send out no tube at all, or, if the germination is stimulated at a low temperature, the growth is so slow that the tube may dry out before reaching the egg sac.

It has been shown by research that pollen grains do not germinate at temperatures lower than 40° F, and even at temperatures below 50° F. the growth of the tube is so slow that a connection between the pollen cell and the egg sac is not effected in under 2 days, though the actual time varies considerably. A high atmospheric moisture during this period is desirable. In practice, of course, the temperature and the moisture vary considerably and it is conceivable that in almost every year a very large proportion of germinating pollen grains fail in the attempt whilst a few that grow under the more favourable conditions complete their growth and establish a contact. The proportion that do so in each year must vary according to the weather conditions.

When the aforesaid contact has been established, the male gametes of the pollen cell travel down the tube, enter the sac, and fuse with the egg cell, a process known as fertilisation.

Providing the nutrition of the egg cell is adequate and properly balanced, the fertilised eggs soon begin growth and cause a swelling of the green base by which sign growers recognise that the blossoms have set their fruit.

The blossoms on a fruit tree are many and if all were fertilised and set fruit, it would be found that the tree would be quite unable to carry the crop. Actually only a small percentage of blossoms need to be "set" to give a full crop.

Research workers in the U.S.A., from an actual count, found that a 10 per cent. set gave a full crop, whilst Crane at the John Innes Horticultural Institution (London) found that a 5 per cent. set was sufficient for a full commercial crop. By spreading the time for maturing their pollen grains over many days, by having their stigmas receptive also over many days, and producing numbers of each far larger than could possibly be needed, the blossoms have provided for a considerable loss of their numbers without thereby causing a loss of crop.

It is only in years of exceptionally unfavourable weather—intense cold combined with continued dry winds—that the set is reduced below the "five per cent." When these unfavourable years come and bring their resultant small fruit crops, there is an outcry for means of protection against frost damage, and as a conclusion to this paper it is proposed to set out the views that are held at present on orchard practices for frost protection such as (*a*) smoke screens, (*b*) spraying, and (*c*) heaters.

Smoke Screens.

Realising that the earth at night radiates heat to the air the early workers attempted to prevent the escape of this heat by holding it near the ground under a cloud of smoke which could be produced without much difficulty by smudge fires. This smudging for a time was believed in and much practised, particularly in California and Florida. However, when quantitative data of both German and American workers became available for the comparison of temperatures in smudged and unsmudged areas (when the heat factor is eliminated) there was nothing to indicate that a sufficient saving of heat had taken place to make the smudge in itself of any great value; in fact, it was concluded from the investigations that "the retardation of nocturnal radiation by the smoke cloud played an insignificant part in frost protection." These results are surprising, seeing that the practice is of very long standing, for it is said to have been carried out by the Romans, and was much in vogue in the 16th—18th centuries in French and German vineyards.

Covering and Spraying.

The protection of plants from frost by covering them with paper or cloth is effected through saving of the heat otherwise lost through radiation. The efficacy of this method is well known though it does not seem practicable for orchard use. Next came the attempt to protect plants by a water spray, but when this practice was investigated it was found that the sprayed blossoms were the more severely damaged. In fact the ice formation on the surfaces of the blossoms actually hastened the complete freezing and damage of the inside tissues.

Orchard Heating.

Whilst the investigations on "smudging" were in progress it became apparent that the smoke fires did in fact directly warm the air in the vicinity and in consequence the method of protection by orchard heating was tried and eventually found to be successful. It would at first appear impracticable to warm up the air in an orchard and persons unfamiliar with the true situation may be forgiven for believing that the heated air would rise to a considerable altitude and be lost. However, this is not the case. On a clear, calm night there is a relatively thin layer of cold air near the ground and much warmer air above. This condition makes orchard heating possible. The hot gases leave the heaters at a high temperature but rapidly mix with the surrounding air so that actually the whole mass is only slightly heated. This slightly heated air naturally rises, but not far, for it soon meets air from above of the same temperature as itself, when further upward movement is checked. Thus in many cases it may only be necessary to warm up the air of an orchard to a height of 30 to 40 ft.

The choice of the heater depends on many factors. A few large fires have proved ineffective, mainly because the upward movement of the warmed air rising from them is not checked as is the case with heated air from small fires and in addition a current is set up so that cold air is drawn in from outside and the valuable warm ceiling layer becomes broken up.

In those sections of California where orchard heating is practised, one hundred burners to the acre, using 1 gallon each of oil, are the most common. These will burn for from 7 to 10 hours, and in recorded experiments have been effective in keeping the temperature 5° F. higher than that of the unheated areas. Wind is a complication and often makes the heating effect of no avail. Fires of coal, coke, briquettes, wood and other waste products have been tried, but none have been found to give as successful results as oil. These substances often take too long to light and in the interval the temperature sinks too low and the damage is done. When once lit, too, they cannot be put out if (as often happens) the temperature rises, but must be left to burn to the end, when wastage occurs. Oil is free from these objections, for lighting is rapid and any or all of the lamps can be extinguished at any time when the danger has passed.

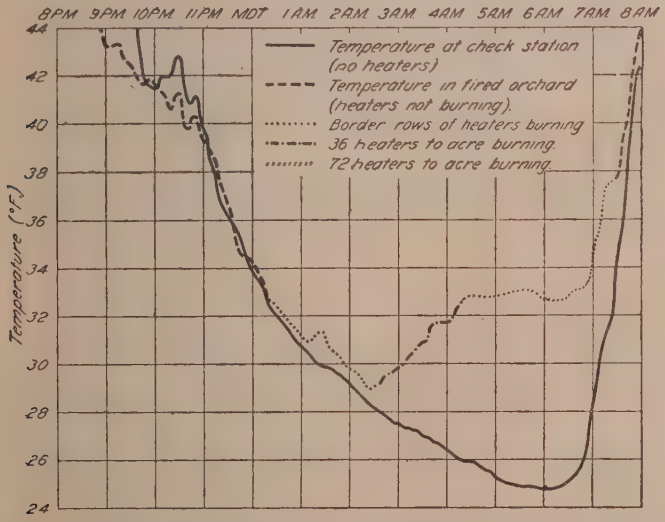

FIG. 1.—Continuous records of the temperature in an isolated 10-acre pear orchard equipped with 5-quart lard-pail oil heaters and at a check station outside. The check-station record indicates what the temperature in the orchard would have been without heating. The temperature was raised 8° F. with 72 heaters to the acre burning. Compare with temperature increase at a larger fired orchard on the same night as shown in Figure 2. Small green apples and pears at the check station were frozen solid on this night

The writer thinks it unnecessary to give an account of the orchard heater, of the brand of oil used, of the arrangements for placing the

pots in the orchards, or of the methods adopted for lighting the heaters, etc., for all particulars of these have appeared in Farmers' Bulletin No. 1588, issued in April, 1929, by the U.S. Department of Agriculture, and in the New Zealand Journal of Agriculture for June, July and August, 1928. It seems, however, essential to the discussion to record the results achieved and the expense involved.

The results are best shown by a reproduction of two graphs taken from the aforesaid bulletin, for these give the results of carefully recorded experiments. The one relates to a 10-acre orchard and the second to a 100-acre orchard.

In the control plot for the 10-acre orchard the temperature steadily dropped from 44° F. at 9 p.m. to 25° F. at 6 a.m., when the small green apples and pears were seen to be frozen solid. In the 10-acre orchard the temperature dropped in a similar way from 44° F. at 9 p.m. to 33° F. at midnight—when the border rows of heaters were lit. The temperature dropped but less sharply so that at 2 a.m. it was nearly 29° F., when 36 burners were started. This arrested the drop in temperature, and in fact secured a rise to above 32° F. by 4 a.m. It was necessary, however, to have 76 burners going from 4 a.m. till nearly 7 a.m. to maintain this temperature after which time all danger had passed. At 6 a.m. the difference between the control orchard and the heated orchard was as great as 8° F., *i.e.*, 25° F. as compared with 33° F.

The notes given on the graph for the 100-acre orchard are self-explanatory; and again show that orchard heating, when properly done, can maintain a satisfactory air temperature even over large acreages. Careful experiments made in New Zealand in 1928 over small areas gave somewhat similar, though perhaps slightly less successful, results.

Cost of Orchard Heating.

No figures of experiments in England are available to show the cost of orchard heating, but many accounts have been published for orchards in the United States. Firstly, there is the question of the number of times that the fires must be lit and this varies for the crop and for the year. To protect citrus orchards during the winter months needs more firing and for longer periods than for deciduous fruits. In one recorded instance, for protecting 281 acres of lemons, the average number of times firing was required over a period of 14 years (1913-1926) was 17, with a minimum of 2 in 1914 and a maximum of 30 in 1923. In protecting orchards of deciduous fruits the average is said be about 5 times annually.

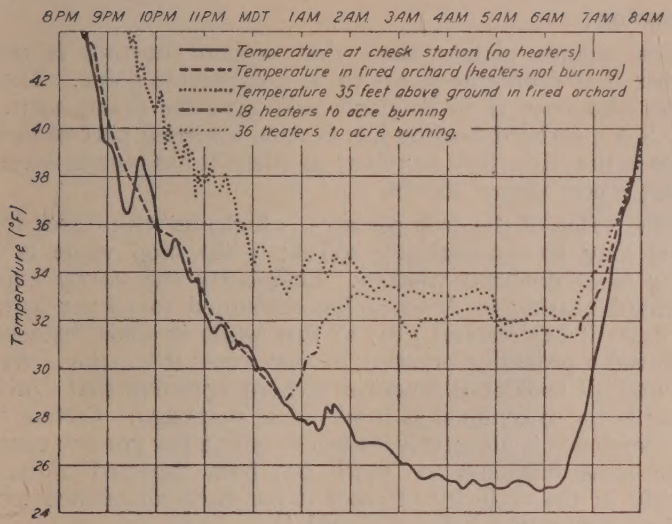

FIG. 2.—Continuous records of the temperature in a 100-acre pear orchard equipped with 5-quart lard-pail oil heaters, and at a check station outside. The check-station record indicates what the temperature in the orchard would have been without heating. The temperature 35 feet above the ground in the orchard equipped with heaters is shown by the dotted line. There was only about half as much temperature inversion on this night before the heaters were lighted as in the record shown in Figure 1. The temperature was raised 7° F. at this location, burning only 36 heaters to the acre. No heaters were lighted at any time during the night in the row in which the temperature station was located. Reserve heaters had to be lighted twice during the night to replace those which were burning dry. The fall in temperature about 3 a. m. and again at 5 a. m. was due to heaters burning low

The cost involved falls under two heads, capital and annual operating costs. A typical cost for 40 acres of pears with simple oil heaters is said to be:—

	Dollars.
Total investment for 40 acres	3,269·00
Total annual cost	944·18
Or average annual cost per acre	23·60

For a 303-acre orchard of apples and pears, in which coal briquettes were used the cost was:—

	Dollars.
Total investment 303 acres	20,848·30
Annual cost per acre	27·89 in 1925
	49·33 in 1926
	39·16 in 1928

Kidson estimates the cost for heating orchards in New Zealand, with oil for three firings only being provided for:—

	2 acres.	5 acres.	10 acres.
Investment	£70 0 0	£156 12 0	£306 15 0
Average running cost per acre	£19 2 6	£18 0 10	£17 12 2

Conclusion.

These figures clearly show that orchard heating is costly. Whether it is profitable seems to be a debatable point. The few growers who tried it in England soon gave the practice up. In the U.S.A., orchard heating has become a settled part of orchard routine in the citrus fruit sections; in others it has been in extensive use, but is now almost obsolete.

If the value of the crop per acre is high, as with citrus fruits, heating may be economically sound; if the crop value is low, heating is of doubtful wisdom. Frequently the yearly expense of orchard heating in America has amounted to £5 per acre; in some cases it has reached £10; so that while in some instances it has proved a profitable practice, in more cases it has not. At any rate, a recent booklet on American orcharding records that "orchard heating is not so common as it was some years ago. Certain areas have abandoned it altogether, in others only a few growers continue it. In some instances too much has been expected of it, but probably in the majority of cases it has been abandoned for the excellent reason that it has not paid."

The high cost of orchard heating and the uncertainty surrounding frost occurrences make it necessary for growers of deciduous fruits to rely more and more on what may be termed frost resistant varieties and it is to this aspect that the attention of research investigators is directed more particularly.

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